CID Cameras: An Overview

Principle of Operation

Charge Injection Device (CID) structure, principle of operation, and readout techniques are fundamentally different from Charge-Coupled Devices (CCD's), providing useful performance advantages. Each pixel in the CID array is individually addressed during readout. Scanning routines are implemented via electronic switching of row and column electrodes which are fabricated in a thin, clear polysilicon matrix over the surface of the array. While CCD's transfer collected charge out of the pixels during readout (hence erasing the image stored on the sensor), CID's do not transfer charge from site to site in the array.

Instead, readout is accomplished by transferring or "shifting" the collected "charge packet" within an individually addressed pixel, and sensing displacement values across the electrodes at the site. Readout is *non-destructive* because charge remains intact in the pixel after the signal level has been determined. To empty the pixel for new frame integration, row and column electrodes are biased to "inject" the charge packet into the substrate collector.

Suspending Readout: The Inject Inhibit Function

Nondestructive readout techniques enhance user control of light integration and image readout, useful for low-light, stop-motion and pulsed-capture applications. The Inject Inhibit (I/I) function suspends imager readout and injection without interrupting normal scanning or image integration. In other words, on-chip scanning and image acquisition proceed, but pixel signal levels are not read and erased.

I/I can be applied to initiate an extended integration mode for multiple-frame, time-lapse exposure enhancement of static low-light scenes. Or it can be used to suspend readout within a single frame time to capture asynchronous high-speed or short-duration events. Images can be captured and "stored" on the imager during a "readout suspended" frame scan, then read out when new frame scanning begins, ensuring full-frame readout of the captured image. Inject Inhibit can also be employed to manage "snapshot" readout from several cameras into a single frame grabber. Camera readout is suspended until each unit is released in sequence for image down-loading.

Non-destructive Readout (NDRO)

In standard CID cameras, a single frame is read out after an extended period of integration, representing the accumulated image. Integration may proceed for milliseconds or up to hours with the addition of sensor cooling, applied to retard accumulation of thermally-generated Dark Current. Implementing Non-Destructive Readout (NDRO) modifications in CID cameras provides a higher level of user control. Camera readout may continue at video rates, but charge injection is inhibited, so the developing image can be viewed on a TV monitor as integration proceeds. This real-time exposure control is especially useful for resolving faint details in low-light scientific applications, significantly expanding dynamic range.

Anti-blooming Performance

At bright intensities, "blooming" describes the distortion in an image that can occur when solid-state video cameras are exposed to concentrated light intensities (Figure 1). Charge can spill from over-saturated elements to adjoining pixels, or the charge transfer mechanisms during readout, eradicating portions of the image. By contrast, CID imagers are more tolerant to intense light because optical overloads are confined to illuminated pixels. Charge is not exported from the pixel collectors, so the structure offers no paths along which overloads can propagate; and radial spreading of charge is minimized as the excess is drawn into the underlying charge collector.

This inherent anti-blooming performance ensures accurate image detail even under extreme lighting conditions, making CID cameras particularly effective for testing and measurement (especially laser analysis), missile tracking, semiconductor pattern recognition, and a wide variety of other applications where reflections and the appearance of specular light intensities give rise to over-saturated regions within a properly exposed image.

Contiguous Pixel Structure, Wide Spectral Response, Radiation Tolerance

The contiguous pixel structure of CID arrays further contributes to accurate imaging, because there are virtually no opaque areas between pixels where image detail can be lost. This attribute is important for applications where precise dimensional data is critical; for instance the determination of object edges for inspection, measurement, positioning, and tracking. It is also essential for applications where complete data is crucial, as in particle analysis where illuminated particles may "disappear" if they "fall into a crack" (opaque region) on the sensor. Employing interpixel processing techniques to achieve sub-pixel resolution, CID cameras are currently utilized in precision gauging equipment performing measurements accurately to half a micron.

The uniform topological structure of the CID imager provides homogeneous pixel-to-pixel response to coherent illumination for more accurate reproduction of laser profiles, ideal for beam analysis and alignment. Camera output is impressively linear, and can be radiometrically calibrated to provide maximum linearity for a given application wavelength. CID imagers offer wide spectral response, from 185 to 1100 nanometers, extending imaging range into the UV and providing near-IR response without blooming, fringing, or loss of data resolution.

Furthermore, the PMOS semiconductor structure of CID imagers reduces radiation effects on imager operation, making CID's less vulnerable to disruption in radiation environments than NMOS devices (structure used in many CCD's). Further hardening can be achieved through special processing.

Camera Scanning Formats

Since each pixel in the CID array is addressed individually, flexible readout and processing options are possible. It is important to note, though, that standard CID imagers utilize sequential addressing circuitry, so standard camera models always scan from top to bottom, left to right (as viewed on a monitor). However, some advanced development CID cameras offer selective image data acquisition utilizing innovative scanning techniques. For maximum flexibility, Random Access CID's (RACID's, currently under development) incorporate address decoders instead of sequential shift registers to provide programmable access to individual pixels in any sequence for readout and special charge manipulation routines. RACID imager functions are computer-directed, providing state-of-the-art acquisition management and control.

Several standard CID camera models feature "Progressive Scan" readout, also referred to as "Sequential Scan" readout, to speed processing by eliminating the delay introduced by 2:1 interlace scanning. Interlaced cameras read out every other row of pixels, meaning there are always gaps in the output. In general, odd and even fields must both be acquired before vision systems can proceed with image processing. Progressive scan cameras, by contrast, read rows of pixels one after another (lines 1, 2, 3, 4, etc.) so the data stream from camera to frame grabber is sequential and comprehensive.

Some CID camera models feature progressive scan, 60 frame per second output for high-speed operation that is nonetheless compatible with RS-170 frame grabbers, TV monitors, and VCR's. Escaping the limitations imposed by RS-170 (TV broadcast) standards, high resolution progressive scan CID cameras provide variable scan mode interfacing, described below, for maximum accuracy, speed and control.

Frame Grabber Interfacing Options

Sequential scan, square pixel format CID cameras simplify computational algorithms and increase processing speed. Interfaced with variable input frame grabbers in the Variable Scan mode (VSC), they provide optimal digitizing stability and repeatability in applications calling for accurate pixel-to-pixel measurements. In VSC mode, the frame grabber (slave) digitizes video based on timing from the camera (master) pixel clock, blanking interval (composite blanking or H drive), and V drive signal. The camera's element rate clock (ERC) is used to synchronously clock A/D readings into discreet memory locations on a one-to-one basis, creating a pixel-lock between camera and frame grabber memory. Pixels are represented in frame memory with a 1:1 aspect ratio; i.e. pixel (x,y) = memory (x,y). There is no spatial distortion of pixel values stored in memory.

By contrast, 2:1 interlace systems interface in Phase Lock Loop (PLL) or Crystal Control modes. In PLL mode, the frame grabber (slave) digitizes video from the camera (master) using an internal clock locked to the camera's H-drive signal. The frame grabber's digitizing clock is likely to be different from the camera's pixel clock. The frame grabber is not pixel-locked. Board sampling rate and memory format determine spatial distortion of pixel values stored in memory.

In the Crystal Control mode, the frame grabber (master) supplies standard RS-170 sync pulses (either composite sync or discreet H & V sync signals) to the camera (slave). Pixels are digitized based on the frame grabber's internal clock. Again, the frame grabber is not pixel-locked. Board sampling rate and memory format determine spatial distortion of pixel values stored in memory.

Unless the camera and frame grabber clock rates are the same, and the pixel array format matches the memory format, over- or under-sampling will occur. Under-sampling takes place when pixel information from the camera is sampled by the frame grabber at a rate lower than the pixel data is clocked out. Example: 755 pixels sampled 640 times results in 640 memory locations filled with data. Each memory location represents 1.18 pixel. Over-sampling takes place when pixel information from the camera is sampled by the frame grabber at a rate higher than the pixel data is clocked out. Example: 512 pixels sampled 640 times results in 640 memory locations filled with data. Each memory location represents 0.8 pixel.

Even when camera and frame grabber formats and clocks match, digitization in the phase lock loop and crystal control modes is subject to pixel jitter (pixel "registration" errors) due to timing inaccuracies between system components that occur during the 63.5 microsecond interval between horizontal sync pulses. The variable scan mode interface eliminates pixel jitter by locking the system to the camera's pixel clock, bringing superior time resolution to the pixel digitizing process.

Scanning Reset: the Frame Reset Function

In applications where full frame resolution is not required but faster capture is, "Frame Reset" is used to decrease vertical frame size for higher frame rates. Applying Frame Reset sends scanning back to the top of the array at the completion of the latest row scan. By counting H drive pulses, the user may reset the camera after scanning a predetermined number of rows. With fewer lines to read, "shorter" frames can be read out faster. Of course, faster frame rates mean shorter integration times, so stronger illumination may be required.

Electronic Windowing: the Rapid Scan Function

For applications where only specific regions in the field of view require attention at any given time, the "Rapid Scan" function is used to isolate areas of interest, establishing "windows" for readout at normal rates while scanning at a very high rate between windows. The selective data extraction speeds imager readout and reduces system data volume, facilitating high-speed processing.

This capability is especially powerful for target acquisition where objects must be tracked at rates up to several hundred images per second as they move within the field of view. Windowing can also be used for on-line inspection. For example, specific sections of a pharmaceutical bottle can be read out for high-speed processing to check cap placement or verify expiration date and lot code.

It is important to note that the rapid scan function can only be implemented with a few commercially available frame grabbers. Windowing uses two horizontal clocks, and most systems can only follow one H clock. Consult with CIDTEC to discuss system options and application considerations.

Asynchronous Clear: the Dump Function

The "Dump" function is used to "empty" all pixels in the imager (via charge injection) just prior to image capture. Since accumulated charge remains in the unscanned rows after a frame reset, the dump function is used to clear the array before new frame capture, removing any shading variations brought about by differences in pixel integration times.

Asynchronous Image Capture

The stop motion or "freeze frame" capability of CID cameras enables them to accurately capture and read *asynchronous* high-speed or short-duration events. An example of this is shown in Figure 2 using a CID camera to capture a fast-moving bottle. CID operation allows image capture to proceed independent of camera timing, so the user times the camera to the event instead of timing the event to the camera's "vertical blanking interval" (period between frames when scanning returns to the top of the array in preparation for new frame readout).

As the bottle travels down the production line, a vision system senses when it has moved into position within the camera's field of view and engages the Inject Inhibit function. Sensor scanning continues, but readout is suspended. However, since the camera optics are stopped down to essentially a black ambient between strobe firings, the system integrates very little background light until the vision system fires the strobe at the appropriate moment, and the image of the bottle is captured by the imager. Scanning continues without readout until the onset of the vertical blanking interval when Inject Inhibit is released, returning the camera to normal operation. Readout of the captured image proceeds at the completion of vertical blanking as new frame scanning begins, providing readout of the complete image. As shown in Figure 2, objects can enter the field of view randomly and the camera will always capture their images in center frame.

The Frame Reset feature, discussed earlier, can be used in this application to increase throughput speed. When the bottle in our example moves into position, the vision system triggers Frame Reset and Dump, resetting the camera for new frame scanning and clearing the array. The strobe is fired during the vertical blanking interval and the image is captured by the imager. Image readout proceeds at the completion of vertical blanking when new frame scanning begins. The vision system resets the camera asynchronously in response to random events, providing almost immediate readout of the captured images.

The same principles of operation apply to asynchronous capture of pulsed lasers. In anticipation of laser firing, frame reset returns the camera to the vertical blanking interval, and dump clears the array. The laser is fired and the image is captured by the imager. Image readout proceeds at the completion of vertical blanking as new frame scanning begins.

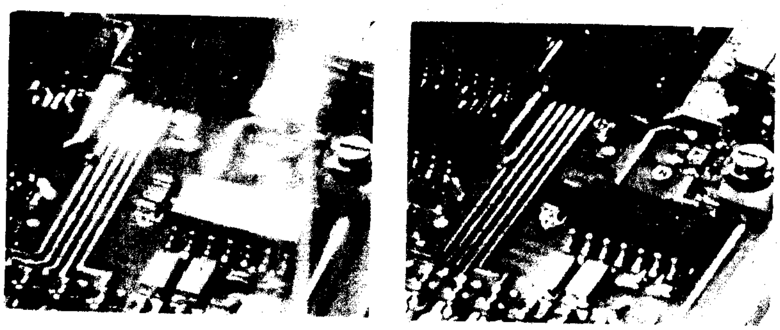

Figure 1.
Unlike many conventional camera images (left), the CIDTEC camera images (right) show virtually no smearing or blooming.

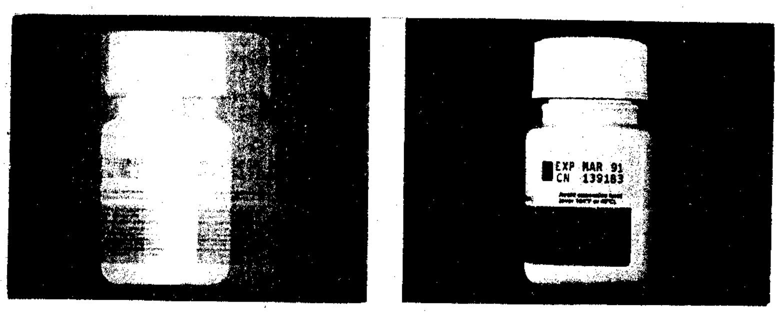

Figure 2.
Typical camera timing does not allow for variations in event timing, leading to positional uncertainty of the captured images as events occur out of sync with the camera (left). Flexible timing and function control of CID cameras provide accurate repeatability for high-speed, asynchronous image capture (right). And CID cameras deliver complete frames for full-frame resolution in stop motion or pulsed applications (not just one field of video as can occur with typical cameras).

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MODEL ICID3710D GATED INTENSIFIED CID VIDEO CAMERA

The ICID3710D is a gated intensified CID camera which consists of a CIDTEC model CID3710D solid state RS-170 version camera, fiberoptically coupled to a 18mm second generation microchannel plate image intensifier. The image intensifier is equipped with photocathode gating, which permits shutter intervals as short as 50ns and makes possible automatic shutter control of camera sensitivity. The gate generator circuit may be operated using TTL level external gate pulses, or internally generated gate pulses. Internally generated gate pulses may be manually controlled, or the "Autogate" function may be used. The image intensifier uses an extremely low noise photocathode, sensitive to the spectral region from 400nm to 900nm. Other options for specific wavelengths response are available (see photocathode spectral sensitivities below).

SPECIFICATIONS

Intensifier Type:	18mm DEP Super GenII
Photocathode:	S-20, S-25, or S-20UV
Phosphor:	P-20, or P43
Sensitivity:	7×10^{-5} lux (faceplate) 10^{-4} lux with F1.8 lens
Light Gain	Typical 10,000x
Resolution:	500 TV lines, 30 lp/mm
Geometric Dist.:	< 1%
Camera Parameters:	Same as CIDTEC CID3710D
Lens Mount:	C-Mount, 1" format
Image Plane Size:	18mm
S/N Ratio:	> 30db at 10^{-4} lux, > 36db at 10^{-3} lux
Dynamic Range:	> 10^4 in Autogate mode
GATE CONTROL	
Autogate:	AGC with >10^4 Dynamic Range
External Trigger:	Gate width manually adjustable from 50ns to 33ms
Continuous:	intensifier continuously on
Input Power:	15VDC @1 amp maximum
ENVIRONMENTAL	
Temp. Range:	0°C to 50°C
Humidity:	0-95% Non-Condensing
MECHANICAL:	
Weight:	Head: 2.3 lb. Controller: 1.5 lb.